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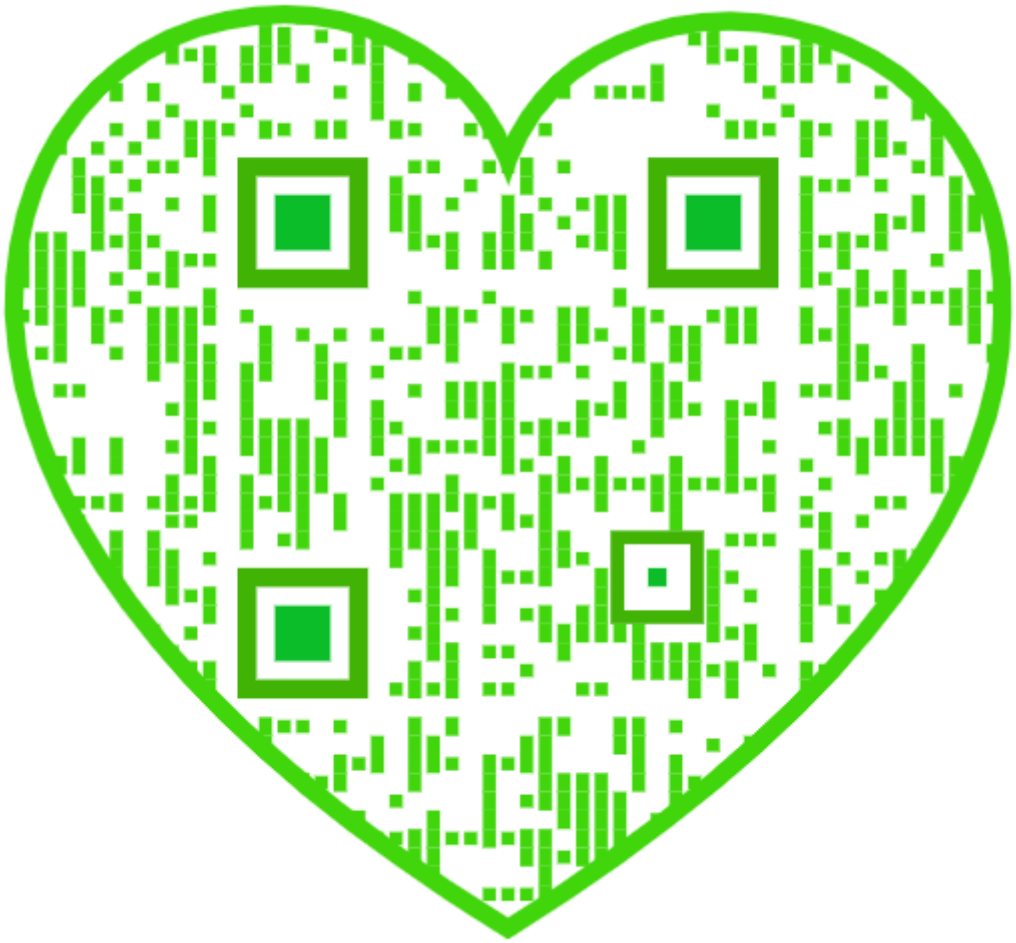

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STATES DEPARTMENT OF AGRICULTURE

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HENRY S. GRAVES, Forester

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THE SEASONING OF WOOD.[1]

By HAROLD S. BETTS, M. E., *in charge, Office of Industrial Investigations.*

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IMPORTANCE OF PROPER SEASONING METHODS.

Practically all wood before being put to use is either seasoned in the air or dried in a kiln. The main objects of seasoning are to increase the durability of the wood in service, to prevent it from shrinking and checking, to increase its strength and stiffness, to prevent it from staining, and to decrease its weight. The sooner wood is seasoned after being cut the less is the chance that it will be injured by the insects, which attack unseasoned wood,[2] or decay before the time comes to use it. Wood that is to be treated with preservatives needs in nearly all cases to be seasoned as much as wood that is to be used in the natural state.

Wood has a complicated structure. The walls of the cells of which it is made up shrink and harden when moisture is removed from them, and unless timber that is to be air-seasoned is piled in the right way, or conditions in the dry kiln are maintained in accordance with certain well-defined physical laws, the material is likely to warp or check, or in some way to be damaged seriously. Until recently proper methods of seasoning received comparatively little attention from manufacturers, and large losses, especially among

[1] For assistance and suggestions given in connection with the preparation of this bulletin, the author is indebted to Mr. D. P. Sexton, of John B. Ransom & Co., Nashville, Tenn., and to Messrs. R. K. Helphenstine, jr., and N. de Witt Betts, of the Forest Service.

[2] The sapwood of seasoned hardwood is subject to attack and frequently to serious damage by powder-post insects. See Farmers' Bulletin 778, "Powder-Post Damage by Lyctus Beetles to Seasoned Hardwood," by A. D. Hopkins and T. E. Snyder, 1917.

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woods that are difficult to dry, were the rule. Sometimes as much as 20 or 25 per cent of the seasoned lumber was rendered unfit for the use intended by defects which had their origin in the drying process. Since the quality of the finished product can be impaired seriously by wrong methods, the importance of right methods becomes apparent.

FIBER SATURATION POINT AND SHRINKAGE.

Water exists in wood in two conditions:[1] (*a*) as free water contained in the cell cavities, and (*b*) as water absorbed in the cell walls. When wood contains just enough water to saturate the cell walls, it is said to be at the "fiber saturation point." Any water in excess of this which the wood may contain is in the form of free water in the

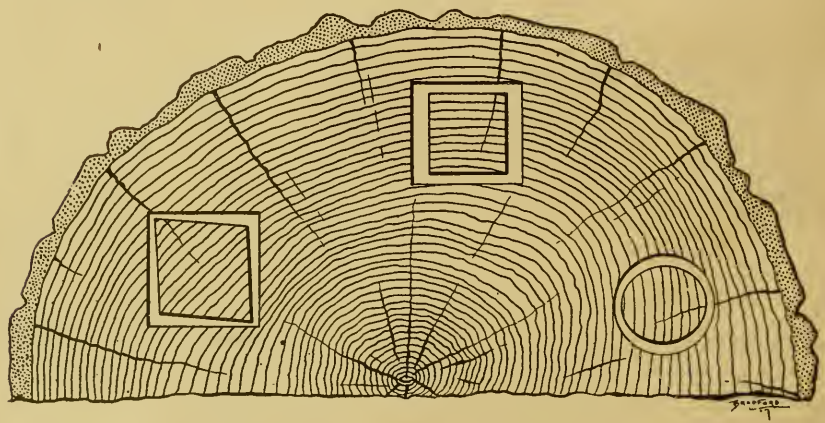

FIG. 1.—Shrinkage as affected by direction of annual rings; approximately twice as great tangentially as radially.

cell cavities. Removal of the free water has no apparent effect upon the properties of the wood except to reduce its weight, but as soon as any of the absorbed water is removed the wood begins to shrink. Since the free water is the first to be removed, shrinkage does not begin, as a general rule, until the fiber saturation point is reached. In the case of eucalyptus and some of the oaks, however, shrinkage begins above this point. For most woods the fiber saturation point corresponds with a moisture content of from 25 to 30 per cent of the dry weight of the wood. Figure 1 shows graphically the difference between tangential and radial shrinkage.

Shrinkage is due to the contraction of the cell walls, and sets up stresses which tend to cause the wood to check. As observed in a cross section of a piece of lumber, shrinkage in the tangential direction is about twice as great as in the radial direction; lengthwise of

[1] The term "sap" sometimes is used wrongly to mean the moisture in wood, and at other times to mean the sapwood. Sap is formed, mainly in the early spring, in the leaves from water rising from the roots through the sapwood. In the leaves this water is converted into true sap, which contains sugar and soluble gums. The sap descends through the bark and feeds the tissues in process of formation between the bark and the sapwood. The heartwood contains no sap.

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the lumber it is very slight. Table I gives the green, air-dry, and kiln-dry weight per cubic foot of the principal commercial woods, and Table II gives the per cent of shrinkage from a green to an oven-dry condition.

TABLE I.—*Average weights of various species of wood.*

Species and locality.	Weights (pounds per cubic foot).		
	Kiln-dry.[1]	Air-dry.[2]	Green.[3]
HARDWOODS.			
Alder, red, Snohomish County, Wash	27	28	46
Ash:			
Biltmore, Overton County, Tenn	38	39	45
Black—			
Ontonagon County, Mich	34	36	53
Marathon County, Wis	34	35	52
Blue, Bourbon County, Ky	39	41	46
Green—			
Richland Parish, La	38	39	47
New Madrid County, Mo	40	42	49
Oregon, Lane County, Oreg	[4]	[4]	[4]
Pumpkin, New Madrid County, Mo	36	37	46
White—			
Stone County, Ark	41	42	47
Oswego County, N. Y	44	46	51
Pocahontas County, W. Va	37	38	46
Aspen:			
Rusk County, Wis	26	27	47
Largetooth, Sauk County, Wis	26	27	43
Basswood:			
Potter County, Pa	26	27	41
Marathon County, Wis	24	25	41
Beech:			
Hendricks County, Ind	43	45	56
Potter County, Pa	41	43	54
Birch:			
Paper, Rusk County, Wis	37	38	51
Sweet, Potter County, Pa	45	47	59
Yellow—			
Potter County, Pa	43	45	56
Marathon County, Wis	43	44	59
Buckeye, yellow, Sevier County, Tenn	24	25	49
Buckthorn, cascara, Lane County, Oreg	35	36	50
Butternut:			
Sauk County, Wis	25	26	45
Sevier County, Tenn	27	28	47
Cherry:			
Black, Potter County, Pa	34	36	46
Wild red, Sevier County, Tenn	27	28	33
Chestnut:			
Baltimore County, Md	29	30	53
Sevier County, Tenn	29	30	56
Chinquapin, western, Lane County, Oreg	31	32	61
Cottonwood:			
Pemiscot County, Mo	[4]	[4]	[4]
Black, Snohomish County, Wash	23	24	46
Cucumber tree, Sevier County, Tenn	33	34	50
Dogwood:			
Flowering, Sevier County, Tenn	52	54	65
Western, Lane County, Oreg	45	47	55
Elder, pale, Douglas County, Oreg	36	37	65
Elm:			
Cork—			
Marathon County, Wis	43	44	53
Rusk County, Wis	43	45	54
Slippery—			
Hendricks County, Ind	42	43	53
Sauk County, Wis	36	37	56

[1] About 8 per cent moisture.
[2] About 12 or 15 per cent moisture. Average condition reached without artificial heating by material sheltered from precipitation, North Central States.
[3] Average green material.
[4] No figures available.

NOTE.—Any individual lot of lumber in the condition specified in the column headings would probably vary 5 per cent from the figures given with a possible variation of as much as 20 per cent. For example, young thrifty pines will have a high moisture content when freshly cut and will probably weigh 20 per cent above the average given.

TABLE I.—*Average weights of various species of wood*—Continued.

Species and locality.	Weights (pounds per cubic foot).		
	Kiln-dry.	Air-dry.	Green.
HARDWOODS—continued.			
Elm—Continued.			
White—			
Potter County, Pa.	35	35	53
Marathon County, Wis.	32	33	45
Gum:			
Black, Sevier County, Tenn.	35	36	45
Blue, Alameda County, Cal.	52	54	70
Red—			
New Madrid County, Mo.	(1)	35	46
Pemiscot County, Mo.	(1)	(1)	(1)
Hackberry:			
Hendricks County, Ind.	38	39	47
Sauk County, Wis.	36	38	51
Haw, pear, Sauk County, Wis.	47	49	63
Hickory:			
Shellbark—			
Sardis, Miss.	47	49	62
Napoleon, Ohio.	55	57	65
Bitternut, Napoleon, Ohio.	47	49	64
Mockernut—			
Sardis, Miss.	47	49	62
Chester County, Pa.	53	55	65
Webster County, W. Va.	(1)	(1)	62
Nutmeg, Sardis, Miss.	42	43	61
Pignut—			
Sardis, Miss.	48	50	62
Napoleon, Ohio.	51	53	64
Chester County, Pa.	52	54	65
Webster County, W. Va.	55	57	63
Shagbark—			
Sardis, Miss.	47	49	63
Napoleon, Ohio.	51	54	64
Chester County, Pa.	45	47	63
Webster County, W. Va.	50	52	65
Water, Sardis, Miss.	44	46	69
Holly, American, Sevier County, Tenn.	39	40	57
Hornbeam, Rusk County, Wis.	35	36	60
Laurel:			
California, Douglas County, Oreg.	(1)	(1)	(1)
Mountain, Sevier County, Tenn.	47	49	62
Locust:			
Black, Sevier County, Tenn.	48	49	58
Honey, Hendricks County, Ind.	49	51	65
Madroña:			
Butte County, Cal.	42	43	66
Douglas County, Oreg.	46	48	59
Maple:			
Broadleaf, Snohomish County, Wash.	32	34	47
Red—			
Marathon, Wis.	37	38	54
Potter County, Pa.	34	36	49
Silver, Sauk County, Wis.	32	34	46
Sugar—			
Hendricks County, Ind.	41	43	54
Potter County, Pa.	42	44	58
Marathon, County, Wis.	42	44	56
Magnolia (evergreen), Winn Parish, La.	34	35	62
Oak:			
Bur, Sauk County, Wis.	43	45	61
California black—			
Butte County, Cal.	37	38	64
Douglas County, Oreg.	(1)	(1)	(1)
Canyon live, Butte County, Cal.	54	56	71
Chestnut, Sevier County, Tenn.	45	46	62
Cow, Winn Parish, La.	48	50	65
Laurel, Winn Parish, La.	45	47	65
Pacific post, Douglas County, Oreg.	(1)	(1)	(1)
Post—			
Stone County, Ark.	46	47	60
Winn Parish, La.	47	49	66
Red—			
Stone County, Ark.	43	45	65
Hendricks County, Ind.	42	44	64
Richland Parish, La.	48	50	67
Sevier County, Tenn.	41	42	61

[1] No figures available.

TABLE 1.—*Average weights of various species of wood*—Continued.

Species and locality.	Weights (pounds per cubic foot).		
	Kiln-dry.	Air-dry.	Green.
HARDWOODS—continued.			
Oak—Continued.			
Spanish—			
Lowland, Winn Parish, La	47	49	67
Highland, Winn Parish, La	40	42	62
Swamp white, Hendricks County, Ind	50	52	69
Tanbark, Willits, Cal	43	44	66
Water, Winn Parish, La	43	45	63
White—			
Stone County, Ark	46	48	59
Hendricks County, Ind	46	47	61
Richland Parish, La	46	48	67
Winn Parish, La	46	47	63
Willow, Winn Parish, La	45	46	76
Yellow—			
Stone County, Ark	43	45	63
Marathon County, Wis	40	42	62
Osage orange, Morgan County, Ind	54	56	62
Poplar, yellow, Sevier County, Tenn	27	28	38
Rhododendron, great, Sevier County, Tenn	39	40	62
Sassafras, Sevier County, Tenn	31	32	44
Serviceberry, Sevier County, Tenn	52	54	61
Silverbell tree, Sevier County, Tenn	31	32	44
Sourwood, Sevier County, Tenn	39	40	53
Sumach, staghorn, Sauk County, Wis	32	34	41
Sycamore:			
Hendricks County, Ind	34	35	51
Sevier County, Tenn	35	36	53
Tupelo, St. John the Baptist Parish, La	35	37	66
Umbrella, Fraser, Sevier County, Tenn	30	31	47
Walnut, black, Kentucky	41	44	58
Willow:			
Western black, Douglas County, Oreg	30	31	51
Black, Sauk County, Wis	25	26	51
Witch hazel, Sevier County, Tenn	45	46	59
CONIFERS.			
Cedar.			
Incense—			
Lane County, Oreg	(1)	(1)	(1)
Weed, Cal	(1)	(1)	41
Port Orford, Douglas County, Oreg	30	31	39
Western red—			
Missoula County, Mont	21	22	24
Snohomish County, Wash	23	24	30
White, Shawano County, Wis	21	21	28
Cypress:			
Bald, St. John the Baptist Parish, La	33	34	51
Yellow, Lane County, Oreg	(1)	(1)	(1)
Douglas fir:			
Plumas County, Cal	30	31	40
Humboldt County, Cal	(1)	(1)	(1)
Johnson County, Wyo	31	32	34
Lane County, Oreg	35	36	39
Chehalis County, Wash	31	32	36
Lewis County, Wash	35	37	41
Washington and Oregon	(1)	(1)	37
Missoula County, Mont	(1)	(1)	(1)
Fir:			
Amabilis—			
Dee, Oreg	(1)	(1)	52
Snohomish County, Wash	26	27	36
Alpine, Grand County, Colo	22	23	28
Balsam, Rusk County, Wis	24	25	45
Grand—			
Missoula County, Mont	28	29	37
Douglas County, Oreg	(1)	(1)	(1)
Noble, Multnomah County, Oreg	27	28	31
White, Madera County, Cal	25	26	56
Hemlock:			
Sevier County, Tenn	31	32	48
Marathon County, Wis	24	25	49
Mountain, Missoula County, Mont	30	32	45
Western—			
Chehalis County, Wash	(1)	(1)	(1)
Grays Harbor and Buckley, Wash	30	31	40

[1] No figures available.

TABLE I.—*Average weights of various species of wood*—Continued.

Species and locality.	Weights (pounds per cubic foot).		
	Kiln-dry.	Air-dry.	Green.
CONIFERS—continued.			
Larch, western:			
Missoula County, Mont.	37	39	51
Stevens County, Wash.	33	34	42
Pine:			
Jack, Barron County, Wis.	29	30	50
Jeffrey, Plumas County, Cal.	27	28	47
Loblolly, Nassau County, Fla.	37	39	54
Lodgepole—			
Grand County, Colo.	27	28	33
Gallatin County, Mont.	27	28	47
Granite County, Mont.	29	30	41
Jefferson County, Mont.	28	29	39
Johnson County, Wyo.	27	28	37
Longleaf—			
Nassau County, Fla.	42	44	51
Bogalusa, La.	[1]	[1]	[1]
Lake Charles, La.	42	43	45
Tangipahoa Parish, La.	39	41	54
Hattiesburg, Miss.	38	40	42
Pitch, Sevier County, Tenn.	35	36	54
Pond, Nassau County, Fla.	38	40	49
Norway, Shawano County, Wis.	32	34	42
Shortleaf—			
Malvern, Ark.	35	36	45
Bogalusa, La.	[1]	[1]	[1]
Slash, Nassau County, Fla.	43	45	53
Sugar, Madera County, Cal.	26	27	50
Table-mountain, Sevier County, Tenn.	36	37	54
Western white, Missoula County, Mont.	29	30	39
Western yellow—			
Coconino County, Ariz.	25	26	44
Madera County, Cal.	28	29	53
Douglas County, Colo.	28	29	49
Missoula County, Mont.	27	28	51
White, Shawano County, Wis.	26	27	39
Redwood:			
Humboldt County, Cal.	23	24	38
Mendocino County, Cal.	26	27	39
Spruce:			
Engelmann—			
San Miguel County, Colo.	22	23	48
Grand County, Colo.	24	25	30
Red—			
Coos County, N. H.	28	29	32
Sevier County, Tenn.	27	28	35
Sitka, Chehalis County, Wash.	[1]	[1]	[1]
White—			
Coos County, N. H.	25	26	28
Rusk County, Wis.	29	30	35
Tamarack, Shawano County, Wis.	37	38	47
Yew, western, Snohomish County, Wash.	43	45	54

[1] No figures available.

TABLE II.—*Average shrinkage of various species of wood.*

Species and locality.	Shrinkage from a green to an oven-dry condition (per cent of dimensions when green).		
	Volume.	Radial.	Tangential.
HARDWOODS.			
Alder, red, Snohomish County, Wash	12.6	4.4	7.3
Ash:			
Biltmore, Overton County, Tenn	12.6	4.2	6.9
Black—			
Ontonagon, Mich	15.2	5.0	7.8
Marathon County, Wis	[1]	[1]	[1]
Blue, Bourbon County, Ky	11.7	3.9	6.5
Green—			
Richland Parish, La	11.7	[1]	[1]
New Madrid County, Mo	13.3	4.6	7.1
Oregon, Lane County, Oreg	[1]	[1]	[1]
Pumpkin, New Madrid County, Mo	12.0	3.7	6.3
White—			
Stone County, Ark	12.6	4.3	6.4
Oswego County, N. Y	14.0	5.3	8.7
Pocahontas County, W. Va	12.6	4.1	6.6
Aspen:			
Rusk County, Wis	11.1	3.3	6.9
Largetooth, Sauk County, Wis	11.6	3.1	7.9
Basswood:			
Potter County, Pa	16.5	6.8	9.9
Marathon County, Wis	14.5	6.2	8.4
Beech:			
Hendricks County, Ind	16.5	4.6	10.5
Potter County, Pa	15.8	5.1	10.6
Birch:			
Paper, Rusk County, Wis	16.3	6.6	8.8
Sweet, Potter County	15.0	6.3	7.6
Yellow—			
Potter County, Pa	16.7	6.9	8.9
Marathon County, Wis	17.0	7.9	9.0
Buckeye, yellow, Sevier County, Tenn	12.0	3.5	2.8
Buckthorn, cascara, Lane County, Oreg	7.6	3.2	4.6
Butternut:			
Sauk County, Wis	9.4	3.6	5.7
Sevier County, Tenn	11.1	3.0	6.5
Cherry:			
Black, Potter County, Pa	11.5	3.7	7.1
Wild red, Sevier County, Tenn	12.8	2.8	10.3
Chestnut:			
Baltimore County, Md	10.4	3.3	6.6
Sevier County, Tenn	18.9	3.4	6.8
Chinquapin, western, Lane County, Oreg	13.2	4.6	7.4
Cottonwood:			
Pemiscot County, Mo	[1]	[1]	[1]
Black, Snohomish County, Wash	12.4	3.6	8.6
Cucumber tree, Sevier County, Tenn	13.6	5.2	8.8
Dogwood:			
Flowering, Sevier County, Tenn	19.9	7.1	11.3
Western, Lane County, Oreg	17.2	6.4	9.6
Elder, pale, Douglas County, Oreg	15.6	4.4	9.0
Elm:			
Cork—			
Marathon County, Wis	[1]	[1]	[1]
Rusk County, Wis	14.1	4.8	8.1
Slippery—			
Hendricks County, Ind	15.5	5.1	9.9
Sauk County, Wis	13.4	4.9	8.7
White—			
Potter County, Pa	14.4	4.2	9.5
Marathon County, Wis	[1]	[1]	[1]

[1] No figures available.

NOTE.—Oven-dry means entirely free from water. The shrinkage from a green to a kiln-dry condition (8 per cent moisture) is generally about 75 per cent of the shrinkage to an oven-dry condition. The shrinkage from a green to an air-dry condition (12 to 15 per cent moisture) is generally about 50 per cent of the shrinkage to an oven-dry condition.

TABLE II.—*Average shrinkage of various species of wood*—Continued.

Species and locality.	Shrinkage from a green to an oven-dry condition (per cent of dimensions when green).		
	Volume.	Radial.	Tangential.
HARDWOODS—continued.			
Gum:			
Black, Sevier County, Tenn	13.9	4.4	7.7
Blue, Alameda County, Cal	22.5	7.6	15.3
Red—			
New Madrid County, Mo	(1)	(1)	(1)
Pemiscot County, Mo	(1)	(1)	(1)
Hackberry:			
Hendricks County, Ind	14.0	4.2	8.9
Sauk County, Wis	13.8	4.9	8.9
Haw, pear, Sauk County, Wis	(1)	(1)	(1)
Hickory:			
Shellbark—			
Sardis, Miss	17.6	7.4	11.2
Napoleon, Ohio	20.9	7.9	14.2
Bitternut, Napoleon, Ohio	(1)	(1)	(1)
Mockernut—			
Sardis, Miss	16.5	6.9	11.4
Chester County, Pa	18.9	8.4	11.4
Webster County, W. Va	(1)	(1)	(1)
Nutmeg, Sardis, Miss	(1)	(1)	(1)
Pignut—			
Sardis, Miss	15.0	5.6	9.8
Napoleon, Ohio	15.3	6.3	9.5
Chester County, Pa	16.9	6.8	10.9
Webster County, W. Va	21.2	8.5	13.8
Shagbark—			
Sardis, Miss	16.0	6.5	10.2
Napoleon, Ohio	18.4	7.9	11.4
Chester County, Pa	(1)	(1)	(1)
Webster County, W. Va	15.5	6.5	9.7
Water, Sardis, Miss	(1)	(1)	(1)
Holly, American, Sevier County, Tenn	16.2	4.5	9.5
Hornbeam, Rusk County, Wis	(1)	8.2	9.6
Laurel:			
California, Douglas County, Oreg	(1)	(1)	(1)
Mountain, Sevier County, Tenn	14.4	5.6	8.8
Locust:			
Black, Sevier County, Tenn	9.8	4.4	6.9
Honey, Hendricks County, Ind	8.6	(1)	(1)
Madroña:			
Butte County, Cal	16.2	5.1	11.7
Douglas County, Oreg	17.6	5.5	11.9
Maple:			
Broadleaf, Snohomish County, Wash	11.6	3.7	7.1
Red—			
Marathon County, Wis	(1)	(1)	(1)
Potter County, Pa	12.5	3.8	8.1
Silver, Sauk County, Wis	12.0	3.0	7.2
Sugar—			
Hendricks County, Ind	14.3	4.9	9.1
Potter County, Pa	14.7	4.8	9.2
Marathon County, Wis	(1)	(1)	(1)
Magnolia (evergreen), Winn Parish, La	12.3	5.4	6.6
Oak, bur, Sauk County, Wis	12.7	4.4	8.8
California black—			
Butte County, Cal	13.6	4.1	6.4
Douglas County, Oreg	(1)	(1)	(1)
Canyon live, Butte County, Cal	16.2	8.0	14.3
Chestnut, Sevier County, Tenn	16.7	5.5	9.7
Cow, Winn Parish, La	19.4	5.9	9.2
Laurel, Winn Parish, La	19.0	3.9	9.5
Pacific post, Douglas County, Oreg	(1)	(1)	(1)
Post—			
Stone County, Ark	16.0	5.7	10.6
Winn Parish, La	16.5	5.2	8.9

[1] No figures available.

TABLE II.—*Average shrinkage of various species of wood*—Continued.

Species and locality.	Shrinkage from a green to an oven-dry condition (per cent of dimensions when green).		
	Volume.	Radial.	Tangential.
HARDWOODS—continued.			
Oak—Continued.			
Red—			
Stone County, Ark	14.5	4.2	8.3
Hendricks County, Ind	13.1	3.7	8.3
Richland Parish, La	(1)	(1)	(1)
Sevier County, Tenn	15.3	3.7	8.3
Spanish—			
Lowland, Winn Parish, La	16.4	5.2	10.8
Highland, Winn Parish, La	16.3	4.5	8.7
Swamp white, Hendricks County, Ind	17.7	5.5	10.0
Tanbark, Willits, Cal	(1)	(1)	(1)
Water, Winn Parish, La	16.4	4.2	9.3
White—			
Stone County, Ark	15.8	6.2	8.3
Hendricks County, Ind	14.3	4.9	9.0
Richland Parish, La	16.0	4.8	9.2
Winn Parish, La	16.9	5.4	9.5
Willow, Winn Parish, La	18.9	5.0	9.6
Yellow—			
Stone County, Ark	14.2	4.5	9.7
Marathon County, Wis	(1)	(1)	(1)
Osage orange, Morgan County, Ind	8.9	(1)	(1)
Poplar, yellow, Sevier County, Tenn	11.4	4.1	6.9
Rhododendron, great, Sevier County, Tenn	16.2	6.3	8.7
Sassafras, Sevier County, Tenn	10.3	4.0	6.2
Serviceberry, Sevier County, Tenn	18.7	6.7	10.8
Silverbell tree, Sevier County, Tenn	12.6	3.8	7.6
Sourwood, Sevier County, Tenn	15.2	6.3	8.9
Sumach, staghorn, Sauk County, Wis	(1)	(1)	(1)
Sycamore:			
Hendricks County, Ind	13.5	5.0	7.3
Sevier County, Tenn	14.8	5.2	7.9
Tupelo, St. John the Baptist Parish, La	12.4	4.4	7.9
Umbrella, Fraser, Sevier County, Tenn	13.0	4.4	12.5
Walnut, black, Kentucky	11.3	5.2	7.1
Willow:			
Western black, Douglas County, Oreg	13.8	2.9	9.0
Black, Sauk County, Wis	13.3	2.2	8.2
Witch hazel, Sevier County, Tenn	18.8	(1)	(1)
CONIFERS.			
Cedar:			
Incense—			
Lane County, Oreg	(1)	(1)	(1)
Weed, Cal	(1)	(1)	(1)
Port Orford, Douglas County, Oreg	(1)	(1)	(1)
Western red—			
Missoula County, Mont	7.6	2.5	4.6
Snohomish County, Wash	8.6	2.5	5.6
White, Shawano County, Wis	7.0	2.1	4.7
Cypress:			
Bald, St. John the Baptist Parish, La	11.5	3.8	6.0
Yellow, Lane County, Oreg	(1)	(1)	(1)
Douglas fir:			
Plumas County, Cal	11.7	4.5	6.9
Humboldt County, Cal	(1)	(1)	(1)
Johnson County, Wyo	10.9	3.7	6.6
Lane County, Oreg	13.2	5.7	7.6
Chehalis County, Wash	12.5	4.4	7.4
Lewis County, Wash	12.3	5.0	8.3
Washington and Oregon	(1)	(1)	(1)
Missoula County, Mont	(1)	(1)	(1)
Fir:			
Amabilis—			
Dee, Oreg	(1)	(1)	(1)
Snohomish County, Wash	14.1	4.5	10.0

[1] No figures available.

TABLE II.—*Average shrinkage of various species of wood*—Continued.

Species and locality.	Shrinkage from a green to an oven-dry condition (per cent of dimensions when green).		
	Volume.	Radial.	Tangential.
CONIFERS—continued.			
Fir—Continued.			
Alpine, Grand County, Colo	9.0	2.5	7.1
Balsam, Rusk County, Wis	10.8	2.8	6.6
Grand—			
Missoula County, Mont	10.9	3.5	6.8
Douglas County, Oreg	(1)	(1)	(1)
Noble, Multnomah County, Oreg	13.6	4.9	9.1
White, Madera County, Cal	10.2	3.4	7.0
Hemlock:			
Sevier County, Tenn	11.6	3.8	7.8
Marathon County, Wis	9.2	2.3	5.0
Mountain, Missoula County, Mont	10.8	4.4	7.1
Western—			
Chehalis County, Wash	(1)	(1)	(1)
Grays Harbor and Buckley, Wash	(1)	(1)	(1)
Larch, western:			
Missoula County, Mont	13.2	4.2	8.1
Stevens County, Wash	(1)	(1)	(1)
Pine:			
Jack, Barron County, Wis	10.4	3.4	6.5
Jeffrey, Plumas County, Cal	9.9	4.4	6.7
Loblolly, Nassau County, Fla	12.6	5.5	7.5
Lodgepole—			
Grand County, Colo	11.3	4.2	7.1
Gallatin County, Mont	11.9	4.6	6.8
Granite County, Mont	11.8	5.0	6.5
Jefferson County, Mont	12.0	5.0	6.9
Johnson County, Wyo	10.1	3.6	5.9
Longleaf—			
Nassau County, Fla	12.2	5.1	6.9
Bogalusa, La	(1)	(1)	(1)
Lake Charles, La	12.8	5.4	7.8
Tangipahoa Parish, La	12.8	6.0	7.6
Hattiesburg, Miss	11.0	4.8	7.5
Pitch, Sevier County, Tenn	11.7	4.8	7.4
Pond, Nassau County, Fla	11.2	5.1	7.1
Norway, Shawano County, Wis	11.5	4.6	7.2
Shortleaf—			
Malvern, Ark	(1)	(1)	(1)
Bogalusa, La	(1)	(1)	(1)
Slash, Nassau County, Fla	12.7	5.9	7.5
Sugar, Madera County, Cal	8.4	2.9	5.6
Table-mountain, Sevier County, Tenn	10.9	3.4	6.8
Western white, Missoula County, Mont	11.5	4.1	7.4
Western yellow—			
Coconino County, Ariz	9.2	4.1	6.4
Madera County, Cal	11.5	4.9	7.3
Douglas County, Colo	9.9	3.8	5.8
Missoula County, Mont	9.3	3.5	5.9
White, Shawano County, Wis	7.8	2.2	5.9
Redwood:			
Humboldt County, Cal	(1)	(1)	(1)
Mendocino County, Cal	(1)	(1)	(1)
Spruce:			
Engelmann—			
San Miguel County, Colo	10.3	3.0	6.2
Grand County, Colo	10.5	3.7	6.9
Red—			
Coos County, N. H	(1)	(1)	(1)
Sevier County, Tenn	11.8	3.8	7.8
Sitka, Chehalis County, Wash	11.2	4.5	7.4
White—			
Coos County, N. H	(1)	(1)	(1)
Rusk County, Wis	14.8	3.7	7.3
Tamarack, Shawano County, Wis	13.6	3.7	7.4
Yew, western, Snohomish County, Wash	9.7	4.0	5.4

[1] No figures available.

HOW WOOD MAY BE INJURED IN SEASONING.

CHECKING.

Checking is caused by unequal shrinkage. If the outside of a piece of wood dries considerably faster than the inside, the surface in time will contract until it can no longer extend around the comparatively wet interior, and so will be torn apart in checks. Checks often are classified as end checks and face checks. End checking or splitting during seasoning causes nearly as much loss as face checking.

CASEHARDENING.

Casehardening or surface hardening occurs when the surface of wood becomes set in a partially dry condition while the interior is still wet. This condition results from too rapid surface drying. If the interior of a casehardened piece of wood dries further, it tends to shrink, while the "set" condition of the surface tends to prevent it from doing so. As a result, stresses are set up in the piece. Plate I, figure 1, shows sections cut from casehardened boards, with a strip sawed from the center of each section. In *A*, the stresses cause the prongs to curve inward and bind on the saw. If the stresses are relieved by treatment with steam, as may be done sometimes, and the board dried a second time, the resawed prongs, as shown in *B*, will curve outward, owing to a reversal of the stresses. This is termed "reverse casehardening." [1]

Plate I, figure 2, shows the form taken by resawed pieces of kiln-dry boards steamed for different lengths of time. In No. 1 the prongs curve inward, owing to casehardening. No. 2 and No. 3 also show a casehardened condition as indicated by the strips curving inward. In Nos. 4, 5, and 6 the casehardening has been eliminated by longer steaming and the resawed strips are straight. No. 7, which has been steamed still longer, shows a condition of "reverse casehardening," in which the resawed strips curve outward.

Sections cut as shown in Plate I may be used also to determine the distribution of moisture in lumber, whether casehardened or not. If not casehardened, such sections will curve inward as they dry if the lumber is wetter on the inside than on the surface, and outward if the reverse is the case. If the lumber is uniformly dry, the prongs will remain practically straight.

HONEYCOMBING.

Honeycombing or internal checking occurs in casehardened pieces when the interior continues to dry and the surface remains fixed. In such cases splits appear in the interior. Plate II, figure 1, shows examples of honeycombing in casehardened pieces.

[1] For further discussion see "Problems in Kiln-Drying Lumber," by H. D. Tiemann, Lumber World Review, Sept. 25, 1915.

WARPING.

Warping or twisting in lumber is due to unequal shrinkage. Some woods are much more subject to warping than others. The trouble can be prevented to some extent by careful piling, both during drying and afterward. Plate II, figure 2, shows badly warped pieces of lumber.

COLLAPSE.

In some woods, notably western red cedar and redwood, when the very wet wood is dried at a high temperature, depressions appear on the surface of the boards, presumably due to the collapse of the plastic cell walls in certain places. If, however, the woods in question are heated above the boiling point while wet, the steam generated in the nonporous cells causes the wood to bulge on the surface. Plate III shows collapse and bulging, or "explosion," as it is termed by the discoverer of the phenomenon.[1]

AIR-SEASONING.

Though the use of dry kilns is increasing steadily, the bulk of our wood is still seasoned in the open air. If kept in the air long enough, the moisture content of the wood finally comes into equilibrium with that of the surrounding atmosphere, and the wood is said to be air-dried. The rate of drying varies, of course, with time of year, species of wood, size and form of piece, and method of piling. Certain of these factors may be controlled or utilized in a way to hasten the drying process and lessen the likelihood of defects appearing in the material.

CROSSTIES, POLES, AND SAWED TIMBERS.

The data in figures 2 to 12, inclusive, collected by the Forest Service[2] in various parts of the country, show the rate at which crossties, poles, and sawed timbers of several species lose moisture when freely exposed to the atmosphere. In some cases it was not possible to weigh the pieces for several days after they were cut. Freshly cut timber loses weight very rapidly in warm dry weather. Ties in some species lose 10 pounds in 24 hours. The rates of seasoning of the various species may be compared by the general trend of the curves. When the curves reach a horizontal position, the material may be said to be air-dry, unless this happens at a time of year very unfavorable for seasoning.

The ties were seasoned in piles of 50 each, and were exposed without cover. The ties on the top of each pile, however, were placed close together and served as a rough roof. The curves are platted

[1] H. D. Tiemann, in charge Section of Timber Physics, Forest Products Laboratory of Forest Service.

[2] See "The Air Seasoning of Timber," by W. H. Kempfer, Forest Service, in Bul. 161 of the American Railway Engineering Association.

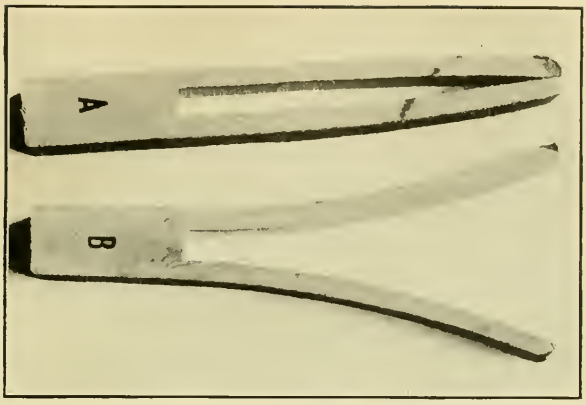


FIG. 1.—SECTIONS CUT FROM CASEHARDENED BOARDS.

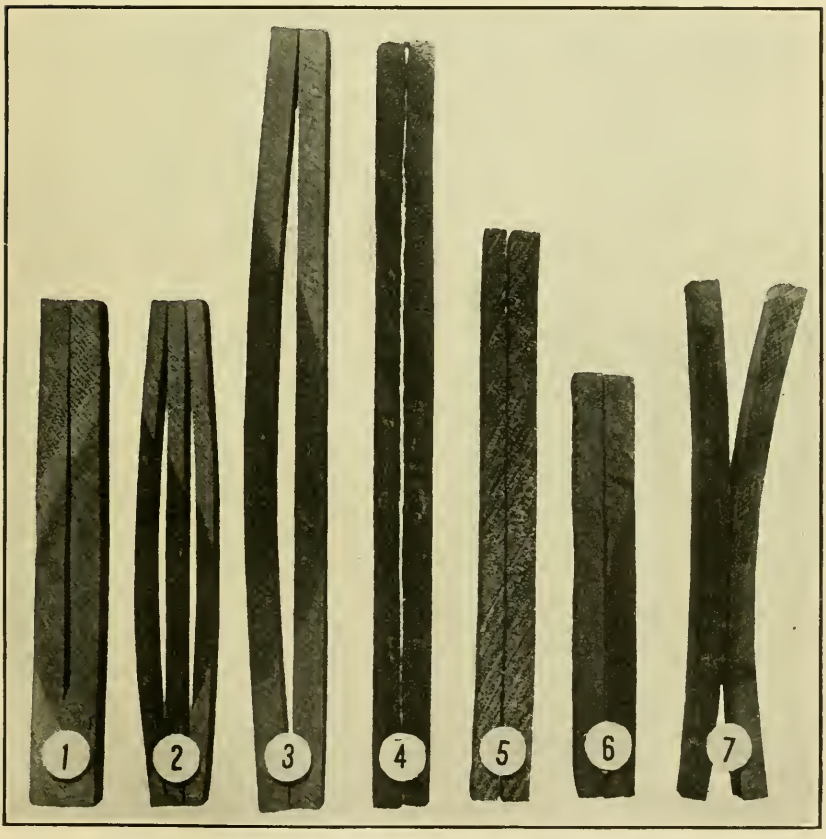


FIG. 2.—RESAWED SECTIONS CUT FROM CASEHARDENED RED GUM BOARDS STEAMED FOR DIFFERENT LENGTHS OF TIME AFTER BEING KILN DRIED.

(1) No final steaming; (2) and (3) 18 minutes final steaming; (4), (5), and (6) 36 minutes final steaming; (7) 3 hours final steaming.

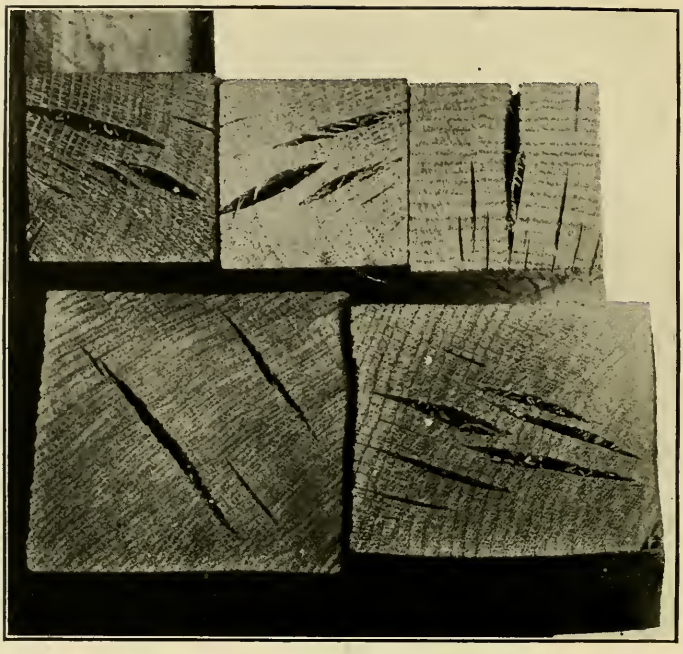
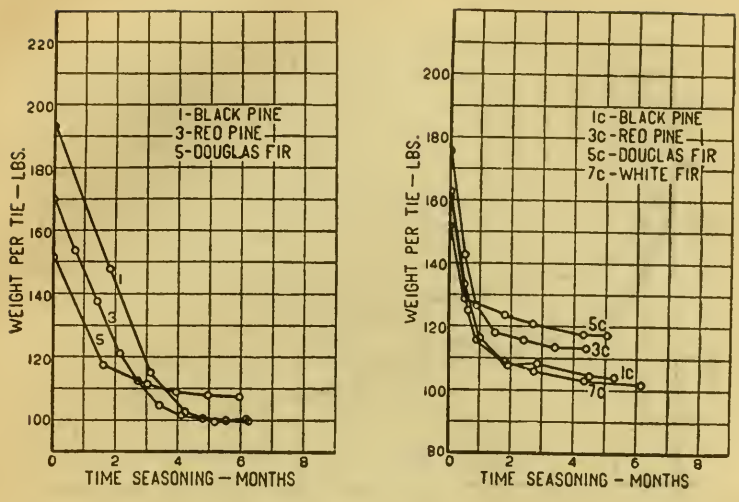


FIG. 1.—HONEYCOMBED OAK TIMBERS, THE RESULT OF CASEHARDENING.

FIG. 2.—BADLY WARPED BOARDS.

The trouble here is due to a poor arrangement of stickers and to the piling together of boards of unequal length.



a. *b.*

FIG. 2.—Southwestern ties. (*a*) Seasoning of ties at Pecos, N. Mex.; cut in January and February; (*b*) seasoning of ties at Pecos, N. Mex.; cut in August, September, and October. (Black and red pine are local names for western yellow pine; black pine refers to young trees and red pine to mature trees).

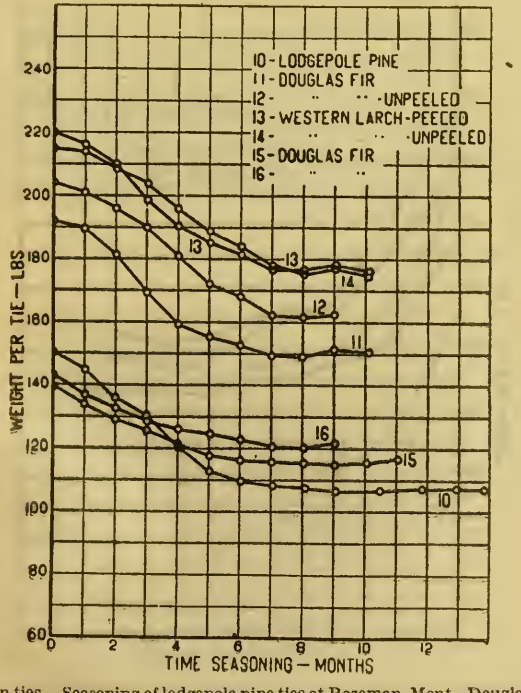


FIG. 3.—Northwestern ties. Seasoning of lodgepole pine ties at Bozeman, Mont., Douglas fir at Sandpoint, Idaho (curves 11 and 12), Pasco, Wash. (curve 15), and Tacoma, Wash. (curve 16); and western larch at Sandpoint, Idaho, cut in January and February; Tacoma ties in December and January.

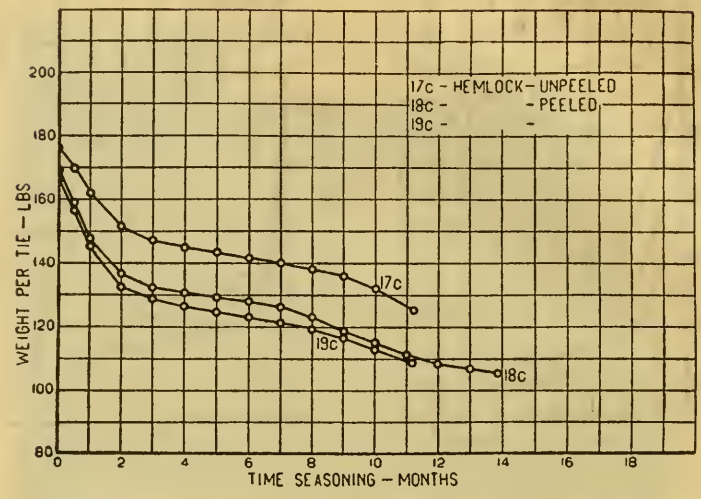


FIG. 4.—Seasoning of hemlock ties at Escanaba, Mich.; cut in August and September.

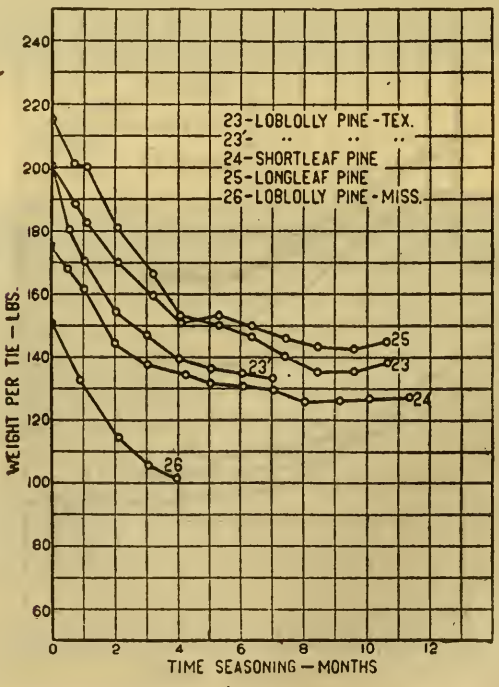


FIG. 5.—Seasoning of ties at Silsbee, Tex., and Ackerman, Miss.; cut in January and February.

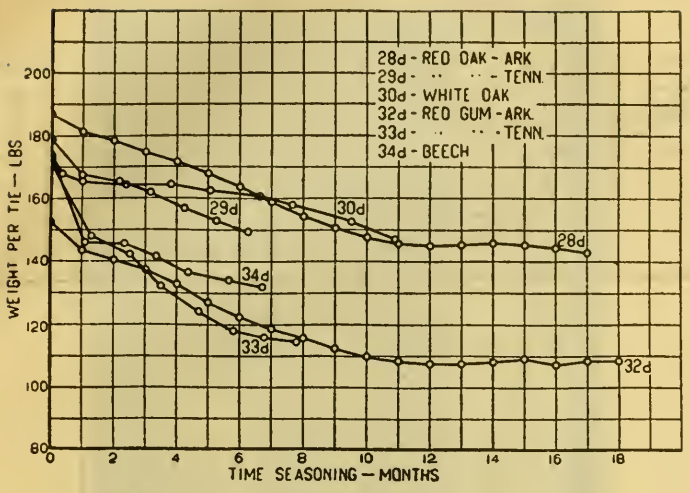


FIG. 6.—Seasoning of hardwood ties in Southern States; cut in October, November, and December.

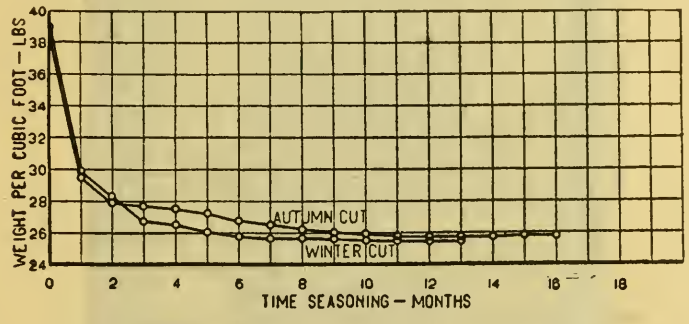


FIG. 7.—Seasoning of southern white cedar poles at Wilmington, N. C.

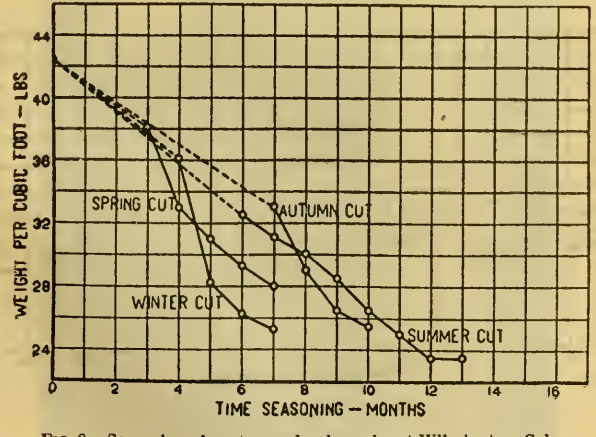


FIG. 8.—Seasoning of western red cedar poles at Wilmington, Cal.

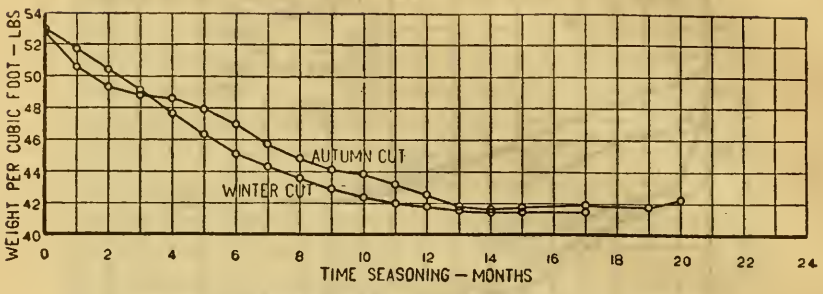


FIG. 9.—Seasoning of chestnut poles at Thorndale, Pa.

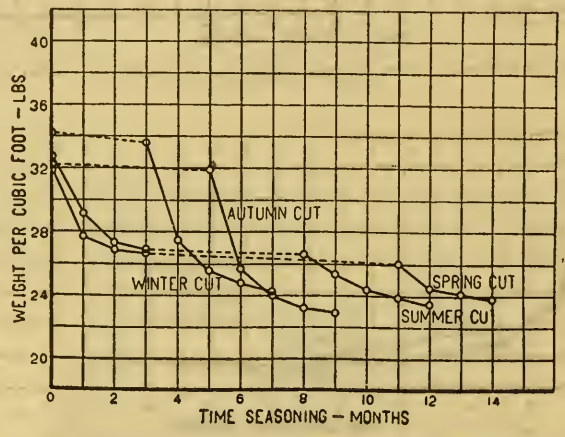


FIG. 10.—Seasoning of northern white cedar poles at Escanaba, Mich.

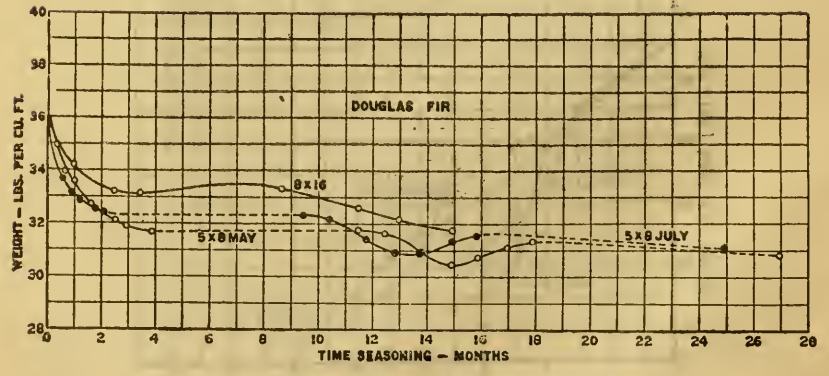
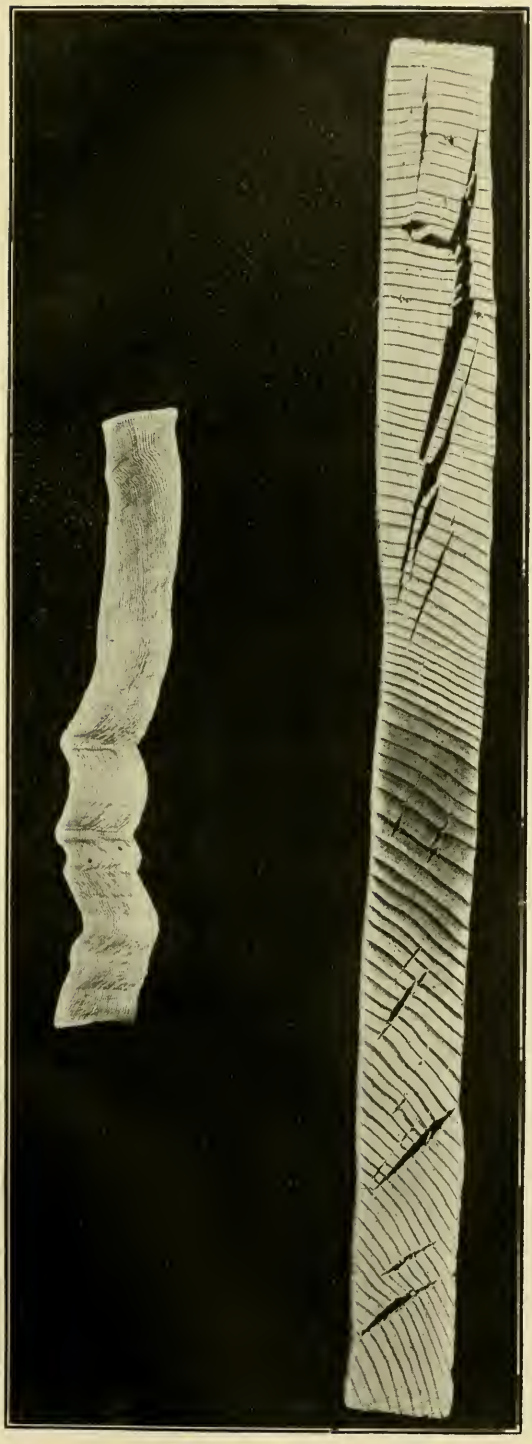


FIG. 11.—Seasoning of Douglas fir timbers at Eugene, Oreg.



COLLAPSE AND BULGE IN VERY WET LUMBER DRIED AT A HIGH TEMPERATURE.

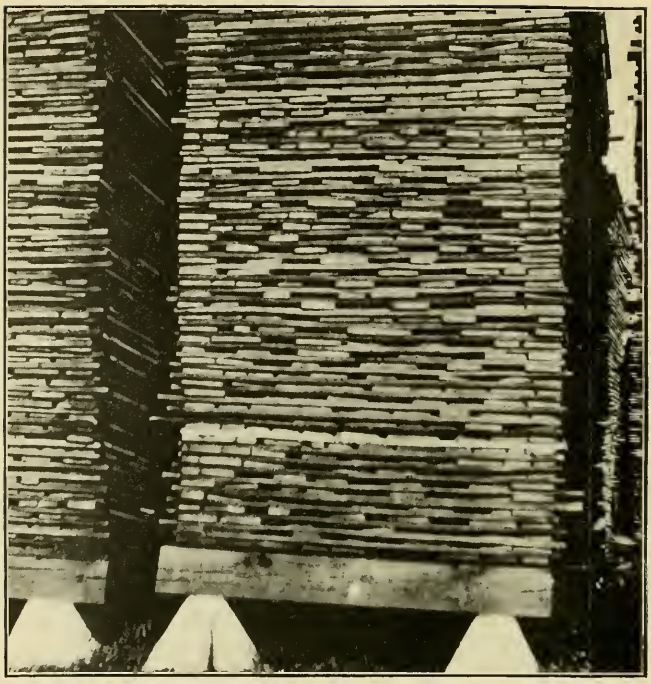


FIG. 1.—CEMENT AS FOUNDATION MATERIAL.

These blocks extend 2 feet above and 2 feet into the ground.

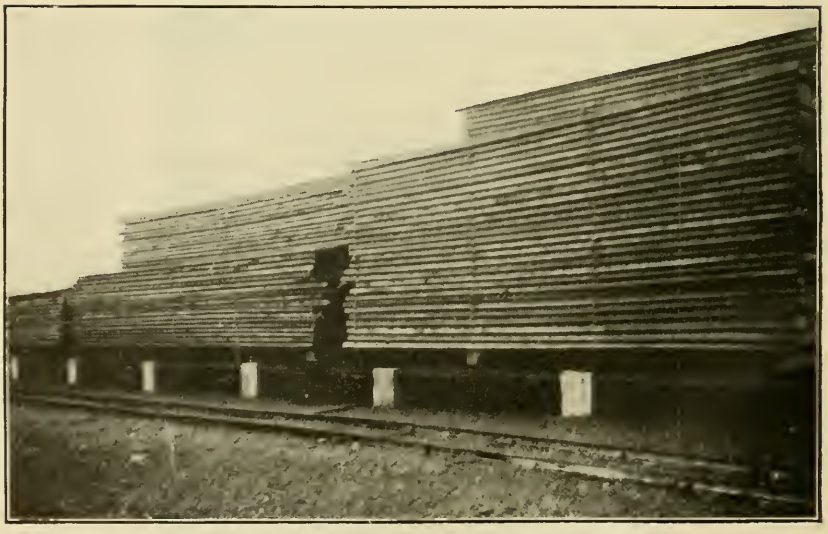


FIG. 2.—ANOTHER TYPE OF PERMANENT FOUNDATION.

Steel rails are embedded in cement piers. The lumber is fully 2½ feet above the ground, insuring excellent ventilation.

from the average weight of the ties. The weight per unit volume could not be used, as in many cases the volumes of the ties were not

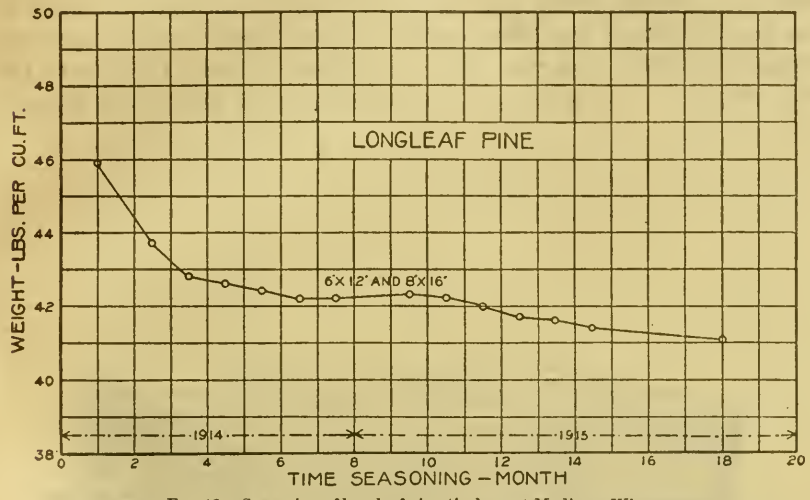


FIG. 12.—Seasoning of longleaf pine timbers at Madison, Wis.

obtained. The poles were seasoned on skids in the open. The sawed timbers were seasoned in open piles under shelter.

LUMBER.

Sawed lumber generally is dried by being piled in stacks with air spaces between the boards. In forming the stacks the boards usually are laid flat, with strips called stickers between courses or layers.

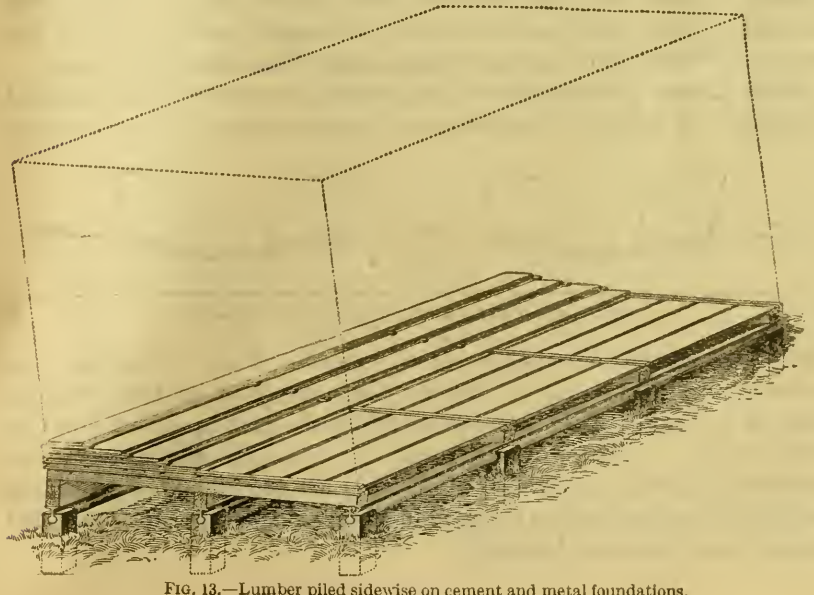


FIG. 13.—Lumber piled sidewise on cement and metal foundations.

A space also is left between each board in a layer and the adjacent board to provide for the circulation of air throughout the stack. Flat or horizontal piling may be of two kinds: (*a*) With the ends of the boards toward the alley—endwise piling, and (*b*) with the sides toward the alley—sidewise piling. Figures 13 and 14 illustrate the two methods. The stacks are arranged to slope from front to rear,

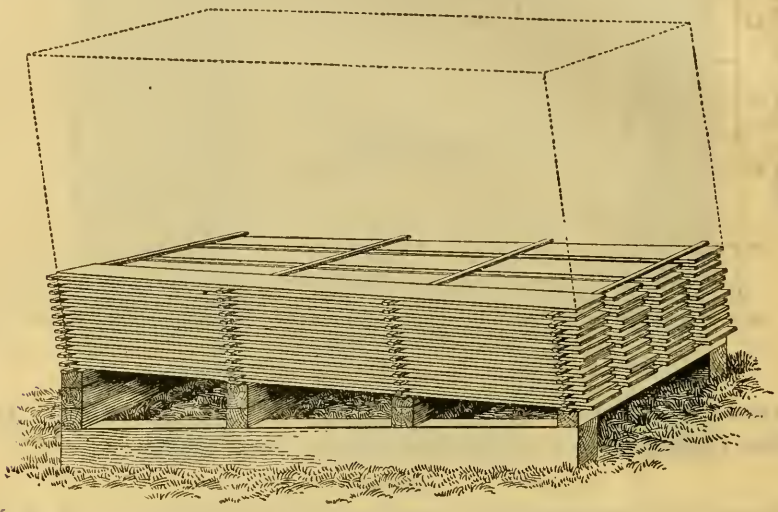


FIG. 14.—Lumber piled lengthwise on wooden foundation.

and to lean forward so that water dripping from the top falls to the ground without trickling down over the courses below. With either method of piling the stacks should be so located in the yard that the prevailing winds blow through them rather than against the ends.

Most lumber manufacturers and dealers use the endwise method of piling. A number, however, have adopted the sidewise method,

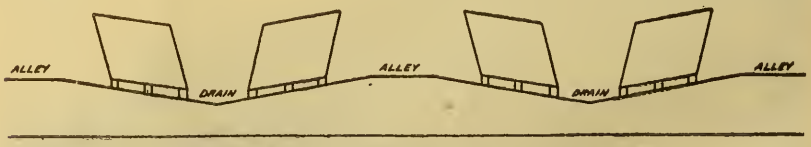


FIG. 15.—Method of providing drainage under lumber piles.

which has certain advantages in the matter of air circulation. In endwise piling the stickers obstruct the passage of air from back to front of a course, while in sidewise piling the passages from front to rear are clear. Water which forces its way into the pile is more efficiently drained in sidewise piling, and the likelihood of sticker rot and discoloration due to the accumulation of moisture, dust, and dirt against the stickers is lessened.

The bottom boards in a stack rest on skids, which in turn rest on foundations, preferably of stone, cement, or metal. Pieces containing rot should never be used for foundation timbers or skids, or allowed to remain in the pile. The vicinity of the pile should be kept clear of weeds.

The use of cement and metal foundations is especially feasible in retail lumber yards and in those maintained by wood-using factories. In retail yards, where economy in space often is the essential thing, the piles are high and a particular space usually is allotted to each class or species of lumber. In factory yards lumber often is held for a number of years before being used. In such cases the frequent renewal of wooden foundations under lumber piles entails considerable expenditure of time and money, to say nothing of the danger of infecting lumber by bringing it in contact with partly rotted foundation timbers. For these reasons foundations of a more permanent character are constantly growing in favor in retail and factory yards. Plate IV shows foundations of this kind.

Sawmill yards, on the other hand, often contain several million feet of material and cover several acres. Lumber coming from the saw generally is piled wherever most convenient, provided it is placed at the distance from the mill required by insurance companies. Economy in storage space generally is not essential, and piles of the same species and kind of lumber are likely to be found in a number of different sections of the yard. In addition, the stock is constantly being turned over, thus giving an opportunity to renew the foundation timbers at comparatively small expense. A number of large lumber companies, however, have adopted cement as a foundation material.

Lumber-storage yards need to be reasonably well drained, or at least the contour of the ground should be such that water will not stand under the stacks after a storm. Otherwise decay is apt to get a start and spread throughout the pile. Where the ground offers but poor natural drainage facilities, some artificial system of drainage usually is employed. Figure 15 shows the system used in the yards of two large lumber companies in the southern hardwood region. This arrangement not only prevents the collection of rain water under the lumber piles, but also gives the required slope to the stack, which on level ground has to be secured by building up the foundations.[1]

A top dressing of cinders has been found satisfactory in some storage yards.

The following set of rules for piling lumber covers the more important points to be observed in the construction of foundations, shape of stack, arrangement of stickers, etc.:

[1] Humphrey, C. J. Timber Storage Conditions in the Eastern and Southern States, with reference to Decay Problems. U. S. Dept. Agr. Bul. 510. 1917.

RULES FOR PILING LUMBER.

1. Foundations (Endwise or Sidewise Piling).

(*a*) The foundations should be strong, solid, and durable.

(*b*) The top of each foundation should be level, and from front to back the top surface of the parallel skids should be in alignment, so that the lumber to be piled will bear equally upon each one.

(*c*) The front foundation should be raised above the second, and the second above the third, to allow a slant in the stack of 1 inch to every foot.

(*d*) The foundations should be spaced not over 4 feet apart, except for heavy planks and timbers.

(*e*) The front foundation should be of sufficient height to provide space for free circulation of air under all parts of the pile.

2. Lumber (Endwise Piling).

(*a*) Skids, preferably 2 by 4 inches, should be laid on top of the foundations.

(*b*) Boards of equal length should be piled together.

(*c*) The ends of the boards should rest upon the front and rear skids.

(*d*) A space of approximately three-fourths inch should be left between boards in the same layer.

(*e*) Lumber piled in the open should have the front ends of boards in each layer slightly protruding beyond the end of the layer beneath, to give a forward pitch to the stack.

3. Lumber (Sidewise Piling).

(*a*) Skids, preferably 4 by 6 inches, should be placed across the foundations at about 4-foot intervals. The number of skids depends upon the thickness of the lumber.

(*b*) Boards of equal length should be piled together.

(*c*) The boards should be placed on the skids, with about three-fourths inch between boards in the same layer.

(*d*) Lumber piled in the open should have the front board in each layer project slightly beyond the board in the layer beneath, to provide a forward pitch to the stack.

4. Stickers (Endwise or Sidewise Piling).

(*a*) Stickers should be of uniform thickness, preferably seven-eighths inch for 1-inch lumber and 1½ inches for 2-inch lumber. Their length should be a few inches in excess of the width of the pile.

(*b*) Stickers should be placed upon the layer of boards immediately over the skids and kept in alignment parallel to the front of the piles.

(*c*) The front and rear stickers should be flush with, or protrude beyond, the ends of the boards.

5. Roof Protection (Endwise or Sidewise Piling).

Cover boards, as a roof protection, should be laid on the top of the pile, extending a few inches beyond the front and rear ends of the stack.

6. Spacing Stacks (Endwise or Sidewise Piling).

Space between the piles should not be less than 2 feet; 4 or 5 feet is preferred if yardage conditions permit.

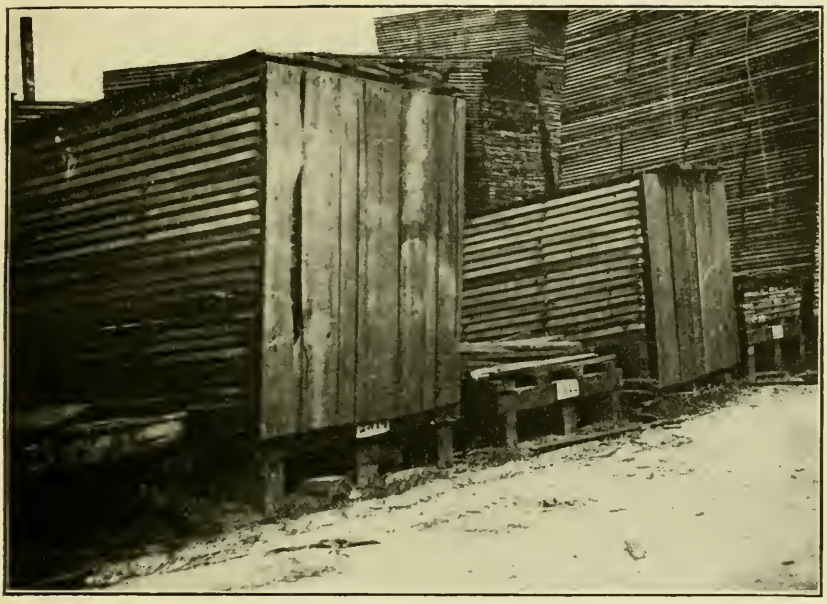


FIG. 1.—SUN SHIELDS USED TO REDUCE CHECKING IN THICK RED OAK TIMBER.

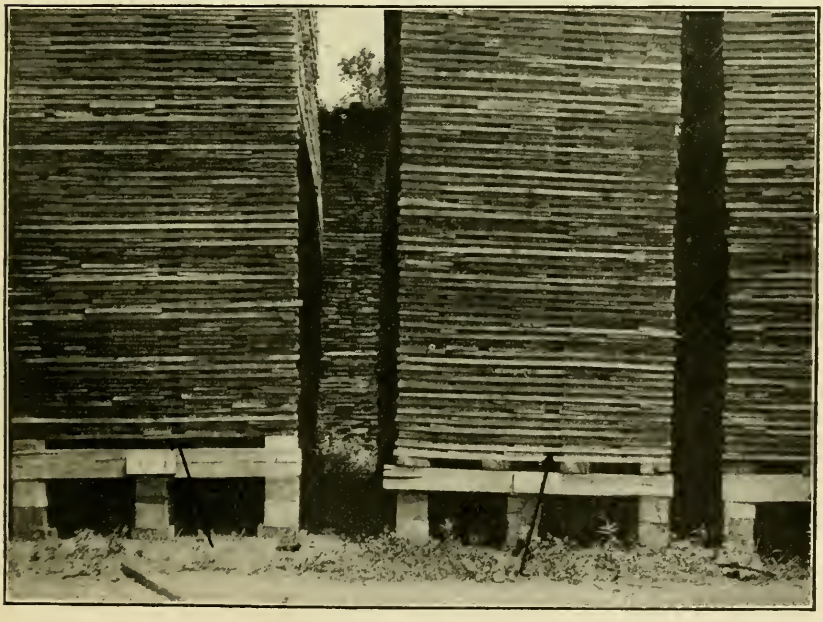


FIG. 2.—LUMBER PILED SO AS TO FORM "CHIMNEY" OR FLUE NEAR CENTER OF STACK FROM BOTTOM TO TOP.

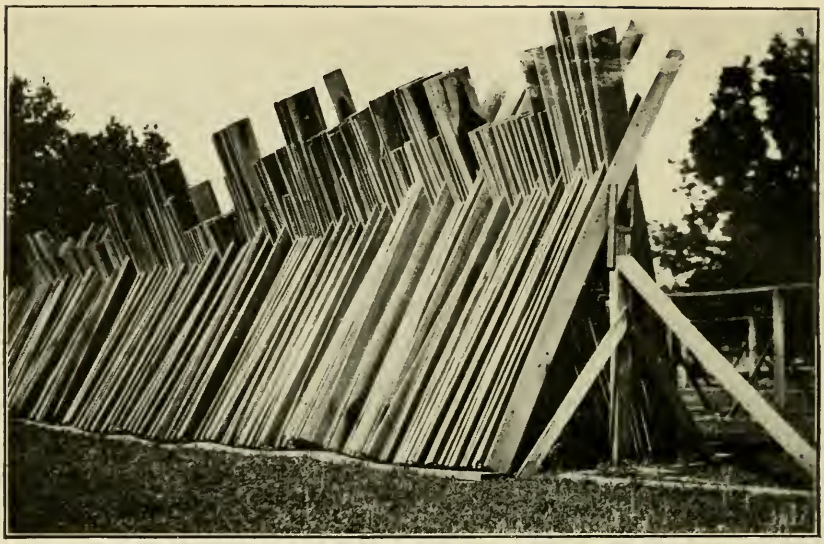


FIG. 1.—POLE DRYING YELLOW POPLAR LUMBER.

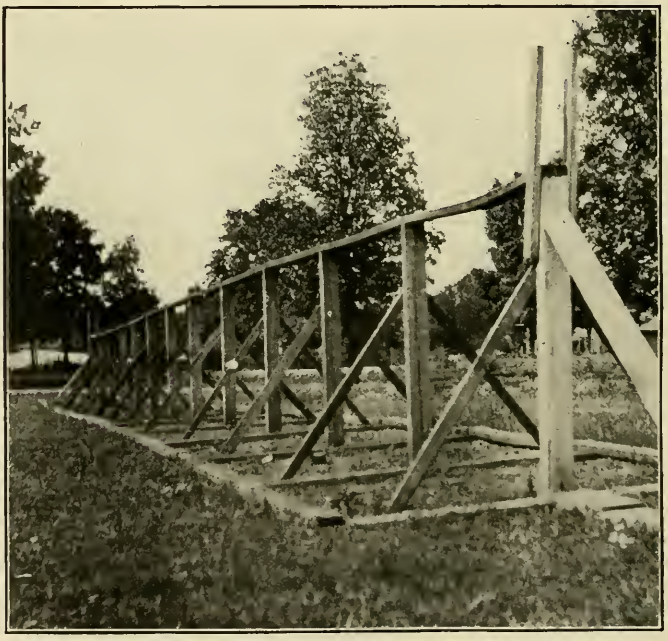
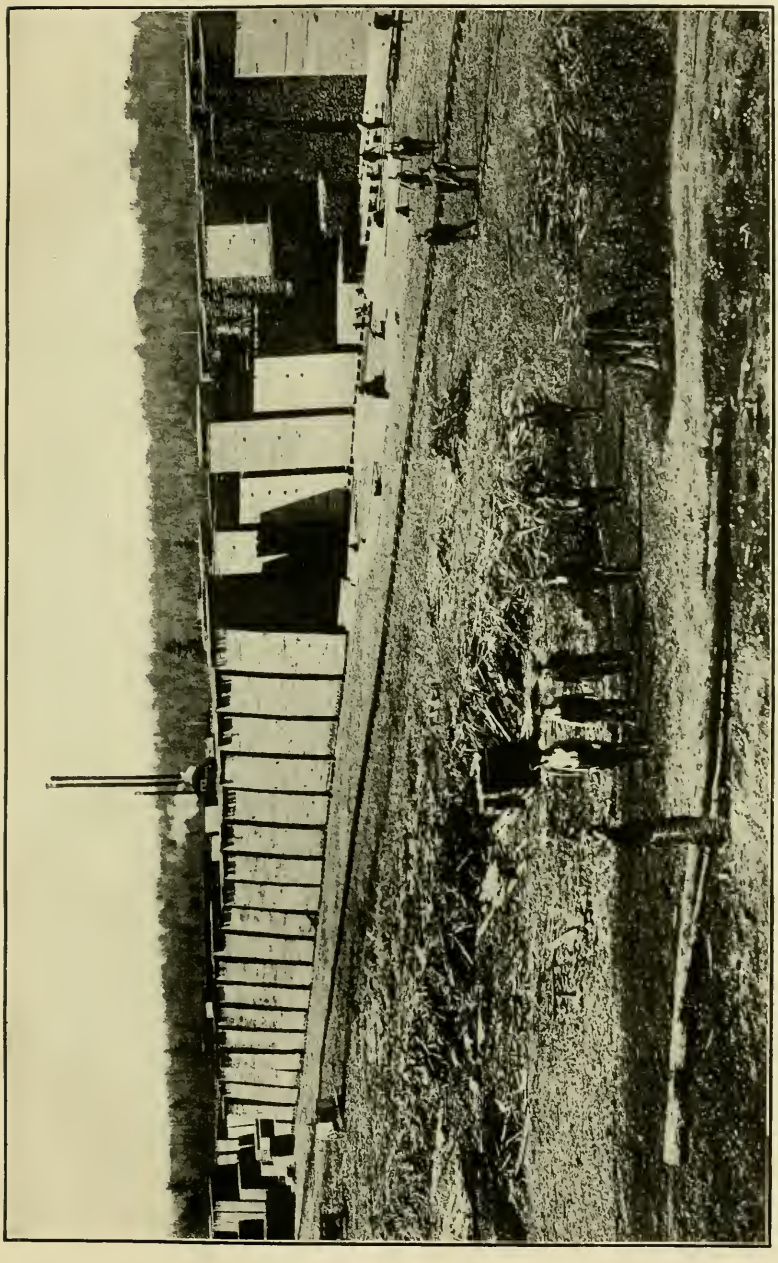
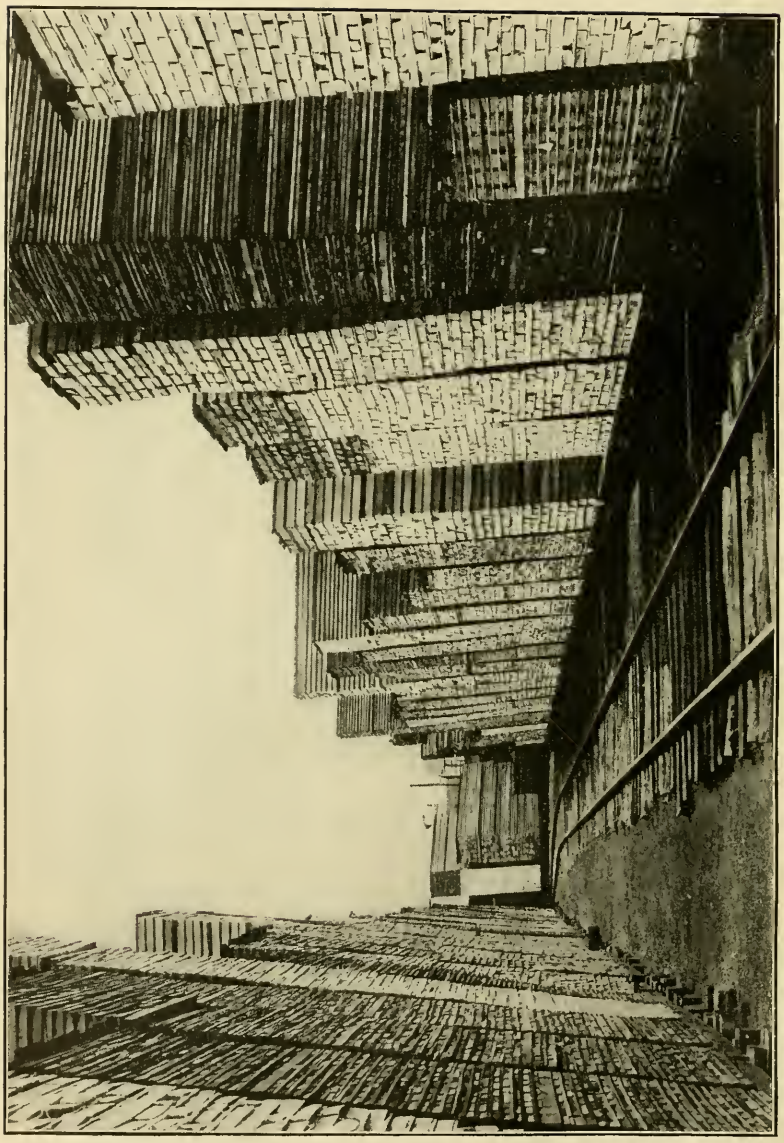


FIG. 2.—POLE FRAMEWORK USED TO DRY YELLOW POPLAR, BASSWOOD, AND COTTONWOOD BEFORE PLACING IT IN A STUCK PILE.



LUMBER YARD OF A SAWMILL IN THE LAKE STATES.

Note fine appearance of lumber piles.



A WELL-KEPT LUMBER YARD MAINTAINED BY A LARGE EASTERN WOOD-USING FACTORY.

Note forward pitch of stacks, treated ends, and general clean sanitary ground conditions.

7. Dimensions of Stack (Endwise or Sidewise Piling).

The customary width of stacks is from 8 to 16 feet. The height is governed by the size and character of the lumber and by the methods of moving it.

8. Treated Ends (Endwise or Sidewise Piling).

The ends of lumber 2½ inches thick or over, unless of the lower grades, should receive a brush treatment of paint or some liquid filler.

The rules just given are based on information obtained through field investigations and from lumber manufacturers and wholesale and retail dealers, and accord with the best lumber-piling practice in general commercial use. Certain species of wood, however, require particular care in air-drying, and in this case slight variations from the rules are necessary in order to secure the best results. Some lumbermen in the South, for example, find that thick red oak checks badly on the ends, and in air-drying such stock have adopted the scheme of protecting it with sun shields, as shown in Plate V, figure 1, which they claim reduces end-checking to a minimum.

Mills cutting red gum formerly experienced difficulty in drying the lumber, on account of its tendency to warp. This objection, however, has been largely overcome by the exercise of care in seasoning. In erecting a pile of gum lumber, stickers are placed every 2 feet apart, some lumbermen claiming that 18 inches in none too close to obtain the best results. Another scheme in more or less general use among gum-lumber manufacturers is to construct the pile so as to have a flue or "chimney" in its center, thus providing ample air circulation vertically through the stack, as shown in Plate V, figure 2.

Green cottonwood, basswood, and yellow poplar lumber is likely to stain badly when piled. Accordingly, a number of lumbermen either end-dry the material or pole-dry it for a week or two and then place it in a "stuck" pile. In end-drying, the boards are stood up on end, edge to edge, under a specially built shed, with stickers arranged horizontally one above the other at specified distances. Such a pile presents exactly the appearance of a regular lengthwise pile of lumber set up on end.

Plate VI, figure 1, shows a quantity of yellow poplar lumber being pole-dried, while Plate VI, figure 2, shows the frame used for the purpose.

Hickory and ash lumber frequently check badly when air-dried. Lumbermen in the southern hardwood region have found that these checks will close up entirely if the lumber is first stuck-piled for 6 to 8 months and then bulk-piled and protected by good covering, preferably sheds.

Plates VII and VIII show lumber piles in yards where careful attention has been given to the matter of piling and yard arrangement.

KILN-DRYING.

Lumber is kiln-dried when there is need for seasoning it quickly, or when the manufacturer does not wish to carry large stocks in his yard. A kiln is used also to further dry partially air-seasoned or even fully air-seasoned material, for special uses.

The main problem in kiln-drying lumber is to prevent the moisture from evaporating from the surface of the pieces faster than it is brought to the surface from the interior. When this happens the surface becomes considerably drier than the interior and begins to shrink. If the difference in moisture content is sufficient, the surface portion opens up in checks.

The evaporation from the surface of wood in a kiln can be controlled to a large degree by regulating the humidity, temperature, and amount of air passing over the wood; and a correctly designed kiln, especially one for drying the more difficult woods, should be constructed and equipped in a way to insure this regulation.

A dry kiln may consist simply of a box in which lumber can be heated, or of a good-sized building or group of buildings (battery) containing steam pipes, condensers, sprays, and various air passages capable of adjustment to regulate the amount of ventilation. The elaborateness of the kiln depends, of course, mainly upon the value of the lumber that is to be dried. For lumber worth $100 per 1,000 board feet, it obviously will pay to use more careful drying methods than in handling material valued at $20 or $25 per 1,000 board feet.

TYPES OF KILNS.

Kilns for drying lumber may be divided into two general classes (fig. 16): (*a*) compartment kilns, and (*b*) progressive kilns. In compartment kilns the conditions are changed during the drying process, and all lumber in the kiln is dried at one time. The conditions at any time during drying are uniform throughout the whole kiln. In a progressive kiln conditions at one end differ from those at the other, and the lumber is dried progressively by being passed through the kiln. Compartment kilns are used when it is desired to dry lumber of various sizes and species, while progressive kilns are used where uniform stock is handled.

The methods of operation generally used in lumber kilns are: (*a*) natural ventilation, (*b*) condensing, and (*c*) superheated steam.

In kilns operating by natural ventilation, the humidity or dampness is controlled by the use of escaping steam and evaporated moisture. Circulation in progressive kilns is largely longitudinal and in compartment kilns transverse. Moist air is allowed to escape from the kiln.

In condensing kilns the humidity is controlled by recirculating the air, which has taken up water from the lumber, across water pipes

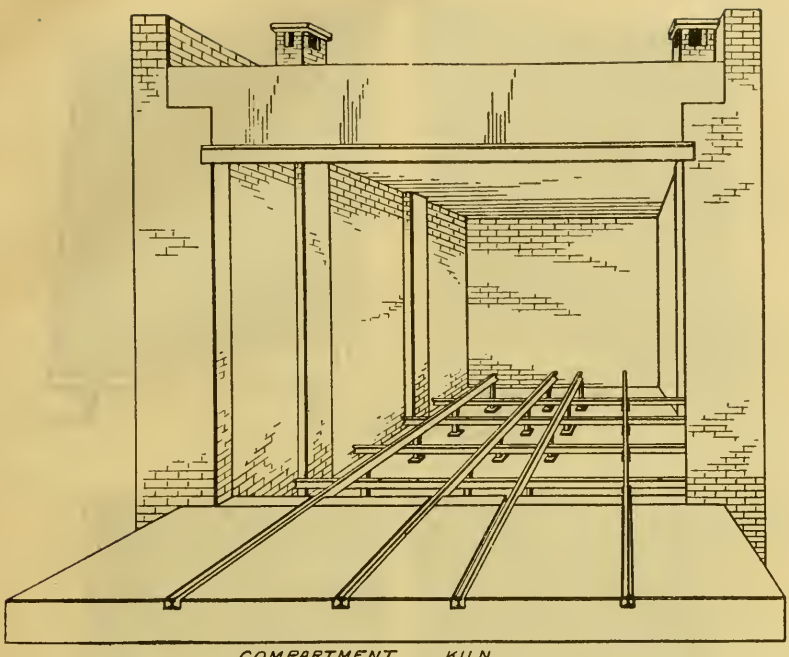


FIG. 16.—Types of kilns.

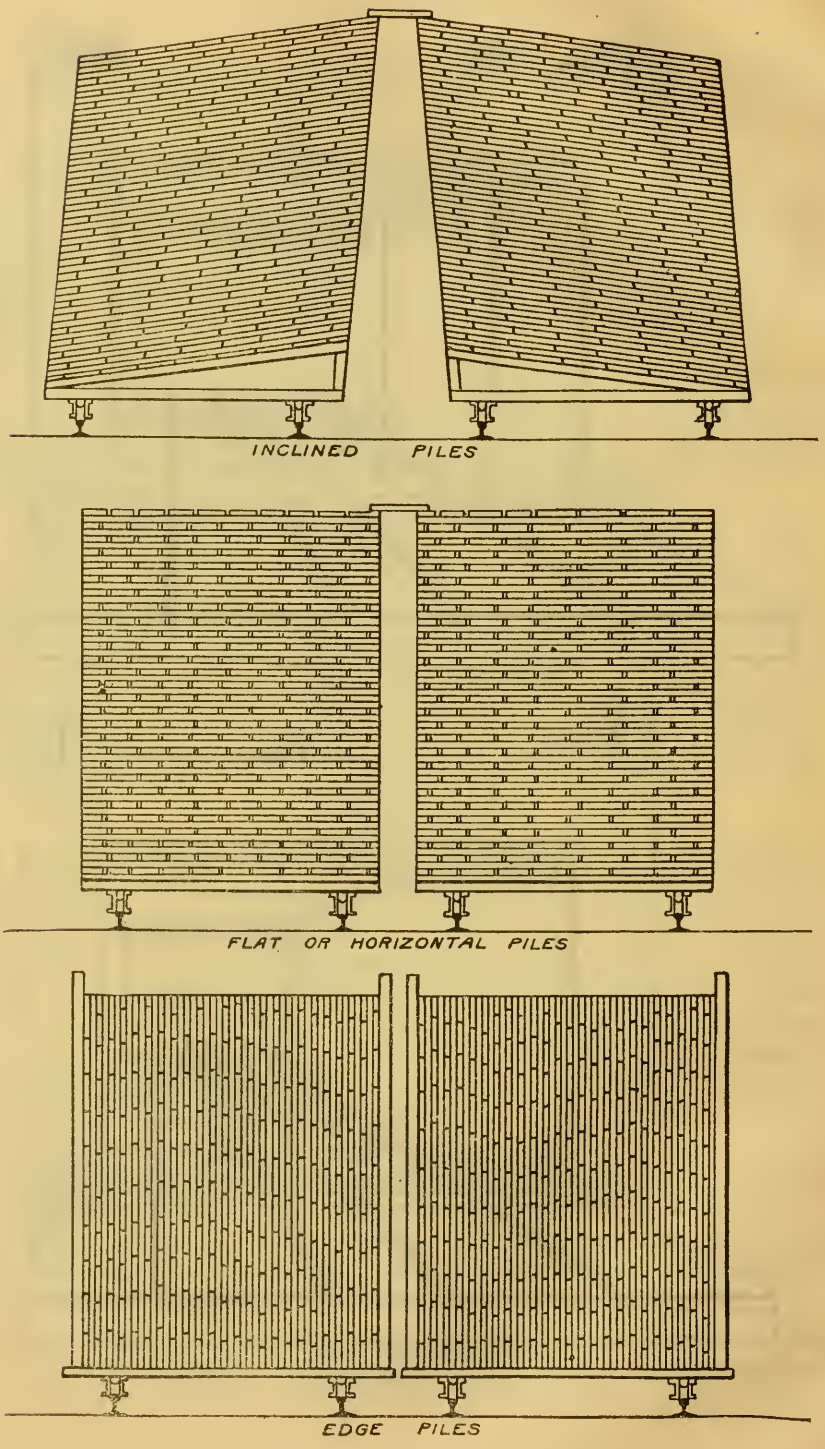


FIG. 17.—Methods of piling lumber for kiln drying.

or through water sprays. The temperature of the pipes or sprays governs the amount of water that condenses from the air, and consequently regulates the humidity of the air when reheated before being passed over the lumber again. The circulation of air may be either natural or forced. Condensing kilns are generally of the compartment type.

Kilns operating with superheated steam are used only where the species to be dried are not injured by high temperatures, and where fast drying is essential.

Lumber may be piled on the trucks which carry it into the kiln in any one of three ways (fig. 17): (*a*) flat or horizontal, (*b*) edge or vertical, and (*c*) inclined. Flat piling is best for longitudinal circulation. It is not so well adapted for transverse circulation, and is not economical for downward circulation. Vertical piling increases the truck capacity, as there are no vertical spaces between the boards. Probably it is the best method for downward or any fast circulation. Provision has to be made, however, for keeping the boards in place in the stack. Inclined piling allows for a definite movement of air either downward or upward (forced draft). It is an improvement, as regards circulation, over horizontal or flat piling.

Some kiln operators using the flat or horizontal method of piling report excellent results from the construction of a V-shaped opening in the center of the truck pile. Such openings are from 2½ to 3 feet wide at their base, and from 3½ to 4 feet high. Where this practice is followed it is customary also to place the boards in the layers closer together as the top of the stack is reached, to force greater lateral circulation.

In loading lumber on kiln trucks by any one of the three methods mentioned, the stickers should be of a uniform thickness and arranged in the piles in alignment.

It is advisable also not to attempt to dry various thicknesses of lumber together. Thick lumber takes longer to dry than thin lumber, and when different thicknesses are mixed the operation has to be governed by the thick stock, to the possible detriment, or at least the unnecessarily long drying, of the thin stock.

PRELIMINARY TREATMENTS.

Lumber to be kiln-dried is sometimes steamed in a separate compartment before being placed in the kiln proper, especially where the kiln is not designed for moist-air treatment. In transferring lumber from a compartment for preliminary treatment to the kiln proper, every care must be used to avoid a sudden change in humidity. The object of the steaming is to heat the lumber and thus make easier the transmission of moisture from the interior to the surface, and also to moisten the surface in case it has become casehardened or "set"

during partial air drying. Other effects, also, are produced, which to a greater or less extent change the properties of the wood. The "sap" in the wood is changed by "cooking," as indicated by a darkening of the wood, the degree of coloring depending upon the temperature and duration of the process. Other changes of a chemical nature apparently also take place in the wood during steaming.

The pressure and duration of steaming desirable in kiln-drying have not yet been thoroughly worked out. Durations of from 5 minutes to 24 hours or longer, and pressures ranging from atmospheric to 50 pounds gauge, have been used in practice. The higher the pressure the greater is the effect produced, and the longer the time the more thoroughly the treatment penetrates the wood. Experiments have shown that a pressure slightly above atmospheric for 24 hours will slightly darken 2-inch maple clear through, and a pressure of 40 pounds will turn oak and probably other hardwoods almost black. Even where the strength of the wood is not the primary consideration, it probably is not safe to exceed 15 pounds gauge pressure (250° F.), except for special purposes.

THE PROCESS OF DRYING.

After the wood has been heated thoroughly in a humid atmosphere, either in the kiln proper or in a separate compartment, it is ready to have the moisture removed by evaporation from the surface. In kiln-drying uniform circulation apparently is the most important thing to be secured. The fact that air when it enters the drying chamber will be cooled, and therefore will tend to fall, should govern the method of piling and the direction of circulation.[1] This means that the air should be allowed and assisted to pass downward through the pile, either by entering at the top of the pile or by an adaptation of this principle to other methods of piling. The rate of evaporation may be controlled best by regulating the amount of moisture in the air (relative humidity) circulating about the lumber in the kiln; it should not be controlled by reducing the air circulation, since a large circulation is needed at all times to supply the necessary heat. Air at 100 per cent relative humidity contains all the water it can carry and has no effect in drying wood. If, however, the humidity is reduced to 90 per cent and the air then passed through a pile of wet lumber, the air can take up a certain amount of moisture. If drying does not progress rapidly enough with the circulating air at 90 per cent humidity, it may be reduced still further. This may be accomplished by ventilation, by condensers, by water or steam sprays, or in a number of other ways. Any well-made kiln which will allow the control of the humidity, temperature, and cir-

[1] See "The Circulation in Dry Kilns," by H. D. Tiemann, Lumber World Review, May 10 and June 10, 1916.

culation of the air passing over the lumber should give satisfactory results. If checking begins during the drying process, the humidity should be increased until it stops. Steam jets in a kiln are often useful for this purpose. In changing the humidity the circulation should not be reduced. A large body of moving air is necessary in order to keep a uniform temperature clear through to the center of each piece of wood in the pile and at the same time supply the heat required for evaporation. If sufficient circulation is not secured, the supply of heat for both purposes will be lacking and the material will not dry uniformly. Figure 18 shows the conditions in a kiln during a run with reference to temperature, humidity, and moisture in the wood. It will be noted that the humidity is kept high at first and lowered gradually. The temperature is held at a certain level for some time and then raised. The moisture is lowered gradually to a final condition of less than 5 per cent.

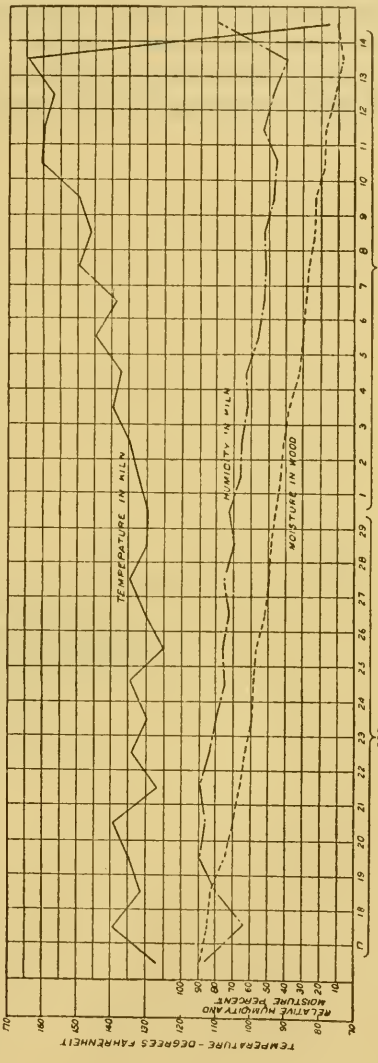


FIG. 18.—Typical conditions in a kiln during a run.

The maximum rate of drying at a given temperature is reached when moisture is evaporated from the surface of the wood just as fast as it is transmitted from the interior. This rate is fixed by the rate of transmission of moisture within the wood and varies with different woods.

The temperature of drying apparently influences the rate of transmission of moisture within the wood. The higher the temperature of the wood the more rapid is the rate of transmission of the moisture, and hence the rate at which the moisture may be evaporated safely. This, of course, applies only to temperatures below those which might result in injury to the wood.

Drying tends to render wood more or less brittle. Although the strength of wood increases with its degree of dryness, yet wood which has been dried and resoaked is less resilient than when green. Therefore, where strength is the prime consideration, it is preferable not to dry the wood beyond the degree at which it is to be used. The final stage of kiln-drying is generally conducted at a humidity somewhat below the actual humidity that on long exposure would produce the same average moisture condition. This is done in order to hasten the drying and to make it uniform throughout each piece.

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